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AD-A032 344

# FGGE and Its Potential Benefits to the Navy

Naval Postgraduate School Monterey Calif

Sep 76

NPS-63Wu76091



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## Monterey, California

FGGE AND ITS POTENTIAL BENEFITS TO THE NAVY

R. T. WILLIAMS

September 1976

Technical Report Period April 1976 - September 1976

Approved for public release; distribution unlimited.

Prepared for: Naval Environmental Prediction Research Facility,
Monterey, California 93940

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT


The objectives and historical background for the First GARP Global Experiment (FGGE) are presented. The required observational systems and the proposed data processing for the experiment are reviewed. The potential benefits to the Navy of a successful FGGE are discussed.


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This task was supported by: Naval Environmental Prediction Research Facility, Monterey, California, 93940

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>NPS-63Wu76091 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>FGGE AND ITS POTENTIAL BENEFITS TO THE NAVY | | 5. TYPE OF REPORT & PERIOD COVERED<br>Technical Report<br>April 1976-September 1976 |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>R. T. Williams | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Naval Postgraduate School<br>Monterey, California 93940 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>N63134-75-PO-50007 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Naval Postgraduate School<br>Monterey, California 93940 | | 12. REPORT DATE<br>September 1976 |
| | | 13. NUMBER OF PAGES<br>29 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)<br>Naval Postgraduate School<br>Monterey, California 93940 | | 15. SECURITY CLASS. (of this report)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FGGE
Global Prediction
Numerical Weather Prediction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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**NAVAL POSTGRADUATE SCHOOL**

DEPARTMENT OF METEOROLOGY **MONTEREY, CALIFORNIA**

NC4(63Ha)/mm

MEMORANDUM 29 October 1976

From: Prof. G. J. Haltiner, Chairman, Department of Meteorology, Naval Postgraduate School, Monterey, California 93940

To: Distribution

Subj: First Global GARP Experiment

Encl: (1) Report entitled, "FGGE and Its Potential Benefits to the Navy"

1. During the past year or so, it became apparent that some components of the data gather systems under development for the First Global GARP[1] Experiment, referred to as FGGE, would not be available in time for use during the experiment. As a consequence, inquiries have been made to the Navy and Air Force to assist in filling the gaps. With decreasing numbers in the armed forces and shrinking dollars due to inflation, commitments to assist in essentially civilian scientific endeavors must be made with great care to avoid any significant diversion from the primary mission of the military.

2. Nevertheless, some substantial benefits would be gained by participation in the experiment to help ensure its success. Global data sets, ranging from the actual observations to highly processed forms, will become available during and after the global experiments. These data will be extremely useful in testing various features of global prediction models and limited area models as well, especially in regions where data coverage is normally sparse. Of course, there will also be enhanced data coverage available on an operational basis during the experiment which should increase forecasting skill and thus improve operational support.

3. I thought it would be valuable to provide more information about FGGE to the geophysics officer community and therefore asked Prof. R. T. Williams, Department of Meteorology, Naval Postgraduate School, who is a member of the Joint FGGE Advisory Panel of the U. S. Committee for the Global Atmospheric Research Program and the Ocean Science Committee, to describe the experiment in more detail. The enclosed report is the result, which I hope will provide information about FGGE and encourage your support of the program when appropriate.

4. Captain J. Johnston USN[2] has been appointed as Navy liaison officer to the FGGE Project Office. He would be pleased to furnish additional information on the Navy participation in the project and would welcome any suggestions from the geophysical community.

G. J. Haltiner

G. J. Haltiner

[1]GARP refers to the Global Atmospheric Research Project which is co-sponsored by the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU).

[2]Capt. J. I. Johnston; Navy Deputy NOAA (FGGE); Rm 1010, WSC-5; 6010 Executive Blvd., Rockville, Maryland 20852.

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## Acknowledgments

The author wishes to thank Professor R. L. Elsberry, Professor G. J. Haltiner, Captain J. Johnston and Commander F. R. Williams for reading the manuscript and for making several useful comments upon it.

## 1. Introduction

A year-long global observation experiment will begin in late 1978. This will be called the First GARP Global Experiment (FGGE), where GARP stands for Global Atmospheric Research Program. FGGE will include two special observation periods during which the observational effort will be intensified. This experiment should yield a global data set of unprecedented coverage, completeness, and scientific and practical value. Research using this data set should yield both new knowledge and practical improvements in operational weather services.

This report will give a brief review of FGGE and will discuss the possible benefits to the Navy from a successful FGGE. Much of the information about FGGE which is reviewed in this report was taken from GARP Publication Series No. 11, although some more recent information is also included. Section 2 will give the historical background for GARP and FGGE. Section 3 will present the objectives for FGGE. The various observational systems which will be used during FGGE will be discussed in Section 4. The plans for data processing are given in Section 5. The potential benefits of a successful FGGE for the Navy will be explored in the last Section.

## 2. Historical Background

In October 1961 the United States National Academy of Science submitted a report to President Kennedy which proposed the following:

(i) An International Atmospheric Science Program,

(ii) An International Meteorological Service Program,

(iii) A World Weather Watch to obtain global data needed to implement the first two programs.

These proposals were incorporated into Resolution 1721 (XVII) adopted by the United Nations General Assembly in December 1961 calling for international cooperation in the peaceful uses of outer space. In particular, the resolution requested the World Meteorological Organization (WMO), in consultation with the International Council of Scientific Unions (ICSU) and other groups, to study measures to:

(i) Advance the state of atmospheric science and technology so as to provide greater knowledge of basic physical forces affecting climate and the possibility of large-scale weather modification;

(ii) Develop existing weather forecasting capabilities and to help Member States make effective use of such capabilities through regional meteorological centers.

The WMO formulated a plan for the World Weather Watch (WWW) and the related regional centers and communication systems. In October 1967 WMO and ICSU agreed to co-sponsor a Global Atmospheric Research Program (GARP). The agreement established the Joint Organizing Committee on GARP (JOC) to oversee the program.

GARP is a program to study those physical processes in the troposphere and the stratosphere that are essential for the understanding of:

- The transient behavior of the atmosphere as manifested in the large-scale fluctuations which control changes of the weather; this would lead to increasing the accuracy of forecasting over periods from one day to several weeks;

- The factors that determine the statistical properties of the general circulation of the atmosphere which would lead to a better understanding of the physical basis of climate.

In order to further these aims one can identify the following elemental scientific problems:

- To determine the predictability spectrum, i.e., what properties are predictable for various time scales and what are the correspondingly relevant space scales;

- To determine what the important physical interactions are in the free atmosphere and in the boundary layer and develop means to parameterize them in terms of the large-scale dependent variables.

A comprehensive and concerted program to solve these problems systematically requires:

(i) Regional observational experiments to acquire the fundamental data necessary for the design and testing of methods for parameterization of the sub-grid scale processes and their interaction with the large-scale motion;

(ii) A global observation experiment to assemble a complete data set appropriate for the study of the behavior of the large-scale motion of the atmosphere for periods from one day to a season;

(iii) Numerical experiments with provisional theoretical models to study hypotheses on predictability and atmospheric energetic coupling, and to test parameterization, observing systems and data assimilation alternatives.

In order to achieve the objectives stated above, the Joint Organizing Committee has found it desirable to establish a series of research and observational programs which are all designed to improve our knowledge and understanding of the behavior of the whole atmosphere or some part of it. The GARP global sub-program (FGGE) has a prominent place in GARP since the large-scale dynamics of the atmosphere is the central theme of GARP. All other sub-programs and related experiments are designed to study regional phenomena or processes which occur in the atmosphere on smaller scales. They include meso-scale, micro-scale and radiative processes as sources and sinks of energy for the large-scale phenomena. An understanding of the interaction between the various scales of atmospheric motion would lead to the development of methods of representing them in terms of parameters which define the large-scale motion. The global sub-program will thus receive an input from all other sub-programs.

### 3. Objectives of FGGE

Theoretical developments and numerical experiments have demonstrated that there is a considerable gap between our present ability to predict the large-scale motion of the atmosphere and the ultimate limit of predictability. It has been recognized that a considerably better knowledge of the global atmosphere is required before we can significantly increase the length of time for which useful forecasts can be made. Also we need a much better understanding of the physical basis of our climate, especially as man's possible effect on the climate becomes of concern.

The first GARP Global Experiment is an attempt to lead the way to the possible limit of deterministic forecasting. It will also provide a world-wide test of how well current general circulation models simulate the present climate.

The following four major objectives justify the aim of having more detailed observations of the global atmosphere than ever before:

(i) <u>To obtain a better understanding of atmospheric motion for the development of more realistic models for extended range forecasting, general circulation studies and climate</u>. Our understanding of planetary scale dynamics is far from complete. Further knowledge is required with respect to ultra-long waves, blocking of the westerlies, the interaction between the tropics and the higher latitudes, and the interaction between the Northern and Southern Hemispheres. The large-scale dynamics in the Tropics require further study, since the GARP Atlantic Tropical Experiment (GATE) covered

only a limited area. Detailed investigations of the monsoon are also required.

(ii) <u>To assess the ultimate limit of predictability of weather systems.</u> Present estimates of the theoretical length of time during which weather systems can be predicted vary from one to three weeks. We need to establish more firmly both the practical and theoretical limits of predictability. We do not know to what extent average weather conditions can be forecast.

(iii) <u>To develop more powerful methods for assimilation of meteorological observations and, in particular, for using non-synchronous data as a basis for predicting the large-scale motion.</u> In order to make maximum use of the data obtained during FGGE it is important that the data assimilation techniques be developed to a high level.

(iv) <u>To design an optimum composite meteorological observing system for routine numerical weather prediction of the larger-scale features of the general circulation.</u> With the aid of the data and the experience from the Global Experiment, it should be possible to determine what the composite global observing system for routine long-range weather prediction should be. Numerical experiments can be made with various models in which one may systematically vary such factors as the density, type of observation, etc., and isolate their effect on the accuracy of the prediction.

In addition to these objectives, it has been decided recently that FGGE should also be used to obtain a better understanding of the physical

basis of climate. This is in fact the second GARP objective. In response to this objective certain other parameters will be measured which are important in determining the climate.

## 4. Observational Systems for FGGE

The JOC has formulated minimum observational requirements which should be met if this experiment is to be a success. These requirements were obtained with the use of appropriate numerical experiments. These requirements are summarized in Table I. The Tropics and higher latitudes are separated and within each region the most important parameters are given first. For example the temperature is the most important in the higher latitudes where the mass field determines the wind, while in the tropics the winds are the more important since they cannot be accurately determined from the mass field. Changes have already been made in the tropical requirements which will be mentioned later.

The FGGE observing system is a composite of several observing techniques, since no single technique can economically satisfy the requirements given in Table I. This observing system can be broken into three parts: (1) The Basic Observing System, (2) The Special Observing System, and (3) The Experimental Observing System. The Basic Observing System is composed of the World Weather Watch (WWW) observation system plus two operational satellite systems. The special observing system will operate principally during two two-month periods, and is designed to fill the critical gaps in the Basic Observing System. The Experimental Observing System is composed of experimental satellites and possibly other research programs.

The Basic Observing System. The World Weather Watch observational network is expected to be upgraded to about 760 upper-air stations and 3000 surface stations. It is important to augment the present WWW system with the addition of new stations and with the addition of wind-finding equipment. These additions are especially important in the

## TABLE I

## DATA REQUIREMENTS FOR FGGE

| Basic Parameters | | Horizontal Resolution (km) | Vertical Resolution | | Accuracy | Frequency* |
|---|---|---|---|---|---|---|
| | | | Troposphere | Stratosphere | | |
| Mid and High Latitudes | Temperature | 500 | 4 Levels | 3 Levels | $\pm 1^{\circ}K$ | 1/day |
| | Wind | 500 | 4 Levels | 3 Levels | $\pm$ 2m/SEC | 1/day |
| | Relative Humidity | 500 | 2 Degrees of Freedom | | $\pm$ 30% | 1/day |
| | Sea-Surface Temperature | 500 | | | $\pm 1^{\circ}K$ | 3 day avg. |
| | Pressure | 500 | | | $\pm$ 0.3% | 1/day |
| Tropics | Wind | 500 | 4 Levels | 3 Levels | $\pm$2m/SEC | 1/day |
| | Temperature | 500 | 4 Levels | 3 Levels | $\pm 1^{\circ}K$ | 1/day |
| | Relative Humidity | 500 | 2 Degrees of Freedom | | $\pm$ 30% | 1/day |
| | Sea-Surface Temperature | 500 | | | $\pm 1^{\circ}K$ | 3 day avg. |

*2 Per Day Would Be Highly Desirable for all Parameters except Sea Surface Temperature.

Tropics where the data is sparse and where separate wind observations are required. Upper-air data should be taken twice a day and surface data up to eight times a day.

The United States is planning to provide 12 moored buoys which will observe sea surface temperature, wave height, atmospheric pressure, temperature, humidity and wind. Approximately 2000 ships will provide surface data, but most of this data will come from the northern hemisphere.

Long-distance commercial aircraft are generally equipped with doppler radar or inertial navigation systems that permit the derivation of the true wind along the flight path. These observations are limited to commercial air routes, which are relatively numerous over the data-sparse areas in the Northern Hemisphere but quite limited in the Tropics and the Southern Hemisphere.

The United States and the U.S.S.R. are each expected to provide two polar-orbiting satellite systems. The U.S. TIROS-N satellites will have a vertical sounder which uses infra-red and micro-wave spectral channels and which will provide temperature soundings from the surface to 1 mb, and water vapor soundings up to the tropopause. On the U.S.S.R. METEOR satellites, infra-red sounders to obtain temperature profiles will also be installed. Both satellite systems will carry scanning radiometers to provide visible and infra-red images of cloudiness a snow and ice cover. The U.S. satellite system will be equipped with a Data Collection and Platform Location System (DCPLS) to receive data from fixed and moving platforms. This system could be used for collecting data from the constant-level balloons and drifting buoys which will be part of the Special Observing System.

Five geostationary satellites are now envisaged to be in operation during FGGE as follows:

| Operated by: | Approximate longitude: |
|---|---|
| ESRO(METEOSAT) | $0^0$ |
| U.S.A.(SMS/GOES) | $75^0$W |
| U.S.A.(SMS/GOES) | $135^0$W |
| JAPAN (GMS) | $140^0$E |
| U.S.S.R. | $70^0$E |

These satellites will have very high resolution visible and infrared sensors for monitoring cloud motions. Cloud motions are determined by measuring the relative displacement of cloud features as a function of time. This process gives cloud velocities which are accurate to two meters per second and the vertical location of the observation is within 100 mb. Most of the cloud targets are at about 850 mb, while cirrus blow-off provides some tracers between 150 mb and 300 mb. Under favorable conditions, clouds at great circle arc distances of $55^\circ$ from the sub-satellite point can be tracked satisfactorily. These satellites can also collect data from platforms whose location is known.

Special Observing System. The Special Observing System will be implemented principally during two two-month-long Special Observing Periods (SOP). During these periods other observation techniques will be used to fill the gaps in the Basic Observing System. Simulation experiments have shown that the winds in the region ($10^\circ$N-$10^\circ$S) will be inadequately represented when only the Basic Observing System is used. This is due to the fact that the wind in this region cannot be specified from the mass field, and because the cloud winds do not give adequate

Table II

WIND REQUIREMENTS IN THE EQUATORIAL TROPICS ($10^{o}$N - $10^{o}$S)

(During the two Special Observing Periods)

| | Horizontal resolution | Vertical resolution | Number of obs/day |
|---|---|---|---|
| Stratosphere | 4000 km | 3 levels | 1 |
| Troposphere | | | |
| Active regions | 350 km | 5 levels | 1 |
| | or | | |
| | 500 km | 5 levels | 2 |
| Inactive regions | 500 km | 5 levels | 1 |
| | or | | |
| | 700 km | 5 levels | 2 |

horizontal and vertical wind coverage. Table II gives the wind requirements for this period which are given in GARP Special Report No. 17. The requirements differ between the active and inactive regions. These regions are different for each SOP.

The United States has been developing a carrier balloon-dropsonde system wh ch would obtain wind data in the (10°N-10°S) zone. However, it has been decided that this system is not sufficiently reliable for use during FGGE. It will be replaced in part by an Omega dropsonde system which will be deployed for long-range aircraft. The Omega dropsondes receive signals from Omega transmitters which can be used to compute wind velocities.

A further source of data in the equatorial belt will be ship-launched Omega-sondes or other ship-launched wind systems. The aircraft dropsondes will be coordinated with the ship distribution.

The Southern Hemisphere has very poor WWW data coverage because of the large ratio of water to land areas. Thus the principal source of data will be satellite temperatures and winds. For this reason a constant-level balloon system has been developed for the region 20°-90°S. The system will be implemented by France and Iran. The constant-level balloons will provide wind, temperature, pressure and geopotential height measurements at one level in the upper troposphere. About 300 balloons are required in each SOP and some of these balloons will be available at later times. The data will be collected by the TIROS-N satellite. It is possible that some constant-level balloons will be used in the equatorial belt to secure data at a higher level.

In the region $50^{\circ}$-$65^{\circ}$S persistent cloudiness makes the reconstruction of temperature profiles and the observation of sea-surface temperatures difficult. For this reason a system of drifting buoys will be introduced. The buoys will measure at least pressure and sea surface temperature although other data would be very helpful. About 300 buoys will be distributed in the zone $20^{\circ}$-$65^{\circ}$S. The data will be collected by the TIROS-N satellite. Ice buoys will be used in polar regions in connection with POLEX.

Experimental Observing Systems. This system is composed of experimental satellites, which will for the most part provide data for the second GARP objective of climate research. The Nimbus-G satellite is expected to provide the following information with a microwave radiometer: ice cover, rainfall rate over ocean, soil moisture, sea surface winds, snow cover and sea surface temperature. This satellite will also be used for the Earth Radiation Budget (ERB) program which will compile global data sets of incoming and outgoing radiation. Ozone data will also be taken. The Seasat-A satellite will obtain estimates of ocean wave heights and winds.

Two GARP regional subprograms are planned for the FGGE period as described in GARP Special Report No. 18. The Polar Experiment (POLEX) will study the physical processes, in polar regions which require parameterization for global circulation models. POLEX, if implemented, should serve the following important FGGE purposes: (1) improve the global data set in the polar latitudes, (2) provide calibration and ground truth for satellite observations, (3) assist in modelling high latitude processes.

The Monsoon Experiment (MONEX) aims at observing and understanding comprehensively the regional and seasonal perturbation of the Indian Monsoon and its effect on the global circulation. It is expected that the Special Observing Periods (SOP) of FGGE will coordinate with the intensive observation periods of MONEX. During the summer monsoon MONEX we will investigate the Arabian Sea effects, monsoon disturbances, the onset of the monsoon, the active and break monsoons, the interaction of the monsoon circulation and other circulation regimes, and mean heat sources and long-term variations. During the winter monsoon, MONEX will stress cold monsoon surges, heavy rainfall and dry spells (Indonesia-Malaysia), and the interaction of winter monsoons and other large-scale circulations. MONEX will also stress orographic and oceanographic effects.

An effort is now being made to coordinate oceanographic programs with FGGE. This should lead to more data for FGGE and better background data for the oceanographic experiments.

## 5. Data Processing

In the planning of the data, collection and processing system, it has been found convenient to introduce the following classification of the main levels in the data flow:

Level I: Raw data (telemetry signals, raw infra-red and micro-wave radiances, cloud images, etc.).

Level II: Meteorological parameters obtained directly from many kinds of simple instruments, or derived from Level I data. This data may be divided into two categories:

Data set IIa: World Weather Watch Operational Data collected through the GTS within the operational cut-off.

Data set IIb: Global Experiment Research Data Set which is distinguished from IIa by a delayed cut-off in order to acquire a complete global data set.

Level III: Initial state parameters. Internally consistent data sets, in grid point form obtained from Level II data by applying four-dimensional assimilation techniques.

Data set IIIa: World Weather Watch Operational Analyses obtained from IIa data.

Data set IIIb: Global Experiment Analyses obtained from IIb data.

Level I data will be normally processed by the facility that takes the data. The Level IIa data will be collected and sent to the World Meteorological Centers (WMCs) on the WWW Global Telecommunications System (GTS). Data received by the WMCs within a specified cutoff time will be analyzed into grid point data for operational use. The Level IIb data will be subjected to four-dimensional data assimilation to produce the Level IIb grid point data.

It is desirable that this process be carried out by more than one technique to make sure that the final data set is not biased by the technique used. It is planned that all Level II and Level III data will be archived so that it will be available for later research.

## 6. Benefits of FGGE to the Navy

A successful First GARP Global Experiment will have many potential benefits to the Navy. The Level IIa data can be expected to benefit the FNWC operational analyses and predictions. The Level IIb and Level IIIb complete data sets should be invaluable for the development and testing of advanced Navy prediction models. The large numerical groups such as National Meteorological Center (NMC), National Center for Atmospheric Research (NCAR), Geophysical Fluid Dynamics Laboratory (GFDL), Goddard Institute for Space Studies (GISS) and University of California at Los Angeles (UCLA) plan to carry out extensive research based on the FGGE data. In addition, NSF expects to fund smaller university research programs which will exploit the FGGE data set. Much of this research will be very valuable to the Navy.

There are three types of errors that occur in numerical forecasts. The first type involves errors in the initial conditions such as inadequate spatial resolution, observational errors or data-assimilation errors. The second class of errors, which are of a mathematical nature, includes inaccurate boundary conditions and numerical truncation errors. The last group of errors is physical, and mainly involves the parameterization of sub-grid sources, sinks and transports of momentum, heat and water. FGGE should contribute to the reduction of all three types of error.

During the Special Observing Periods FGGE will provide the best global data sets which have ever been assembled. This is especially important to the Navy, since it has global prediction responsibilities. This global aspect of the data will only be important to the National Meteorological Center when longer-range forecasts are made, whereas it

will be valuable for the Navy for even short-range forecasts. This data will be invaluable for the development and testing of global prediction models since both the initial and verifying data sets will be essentially free of large-data voids. Data assimilation techniques can be tested and improved with this data. In addition to Navy supported research and development in global analysis and prediction, it is expected that the major numerical modelling groups will make a large effort in this area.

It is especially important for the Navy to develop an accurate prediction model in the Tropics. The GARP Atlantic Tropical Experiment (GATE), which was carried out in 1974, has provided a wealth of data which will significantly increase our knowledge of the interaction between surface layer fluxes, cumulus convection and the smaller-scale synoptic disturbances. FGGE will provide Tropical data on scales from the synoptic scale up to the planetary scale. These scales were not covered by GATE. It is expected that research carried out with FGGE data (especially during the SOPs) will lead to significant improvements in Tropical prediction models. It has been demonstrated with GATE data (the Florida State University group and the British Meteorological Office group)[1], that good forecasts of the smaller-scale synoptic disturbances can be made if the initial data is adequate. Extensive tropical research will be carried out during FGGE, both in understanding the physical processes and in prediction model development. Elsberry (1975) has discussed tropical storm prediction with numerical models. During the SOPs it is unlikely that many tropical storms will be observed. However, the progress

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[1]Results presented at the GARP Study Conference on tropical numerical modelling, Exeter, England, April 1976.

which is expected to be made in larger-scale tropical prediction should improve tropical storm forecasts by improving the prediction of the currents in which the tropical storms are imbedded.

Extended range forecasts (say up to 10 days) which show skill over climatology would be very useful to the Navy for ship routing. One of the principal objectives of FGGE (see Section 3) is the development of models for extended range prediction. The global coverage of the FGGE data set is necessary for the development and testing of these models. The use of this data will minimize the errors due to poor initial data which will allow the model errors to be isolated. Once the model errors are isolated, the numerical errors can also be reduced by increasing the resolution. Thus the physical errors mentioned above can systematically be reduced. Phillips[1] has pointed out that the general circulation models employed by GFDL, GISS and NCAR all have certain errors in common when integrated over two-week periods. These errors include: under-prediction of eddy kinetic energy, systematic temperature errors, too strong zonally averaged jet streams, and errors near the top of the model domain. As these errors are reduced through model improvements, the FGGE data set can be used to gage the model improvement. A large amount of research will be carried out in the United States and in other countries on extended-range prediction. This should greatly assist the development of a Navy extended-range prediction model.

Another important use of the FGGE data set will be to carry out impact studies which will indicate the forecast error caused by deleting certain observational data from the initial data set. In this way one

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[1] Presentation at FGGE Workshop A, Princeton, N.J., November 1975.

can isolate the effect of density, type of observation, etc., on forecast accuracy. From these studies it should be possible to design an optimum composite meteorological observing system for routine prediction of the larger-scale features of the general circulation. This type of research should be especially valuable to the Navy. For example, if the Navy requires a more accurate forecast over a certain region, then an impact study could be made to estimate the forecast improvement which would result from a locally augmented observation system.

In summary, a successful FGGE will have many potential benefits to the Navy. The FGGE data will improve FNWC operational forecasts during the experimental period. It is recommended that each Navy forecast unit be asked to evaluate the impact of the new data during FGGE on their operations. These evaluations would be very helpful in developing a five-year plan for environmental prediction. The complete final data sets will be invaluable to the development and improvement of Navy numerical prediction models. The global aspect of FGGE is especially important to the Navy, because of its global forecast responsibility. The research carried out by other groups with FGGE data should be extremely useful to the Navy, since it cannot afford to perform all of the research itself.

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(The GARP publications can be obtained from the Secretariat of the World Meteorological Organization, case postale no. 5, CH-1211 Geneva 20, Switzerland.)